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No. 464

A COMPLETE TANK TEST OF A MODEL OF A FLYING-BOAT HULL - N.A.C.A. MODEL NO. 11

By James M. Shoemaker and John B. Parkinson
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By James M. Shoemaker and John B. Parkinson

SUMMARY

This note discusses the limitations of the conventional tank test of a seaplane model. The advantages of a complete test, giving the characteristics of the model at all speeds, loads, and trim angles in the useful range are pointed out.

The data on N.A.C.A. Model No. 11, obtained from a complete test, are presented and discussed. The results are analyzed to determine the best trim angle for each speed and load. The data for the best angles are reduced to nondimensional form for ease of comparison and application.

A practical problem using the characteristics of Model No. 11 is presented to show the method of calculating the take-off time and run of a seaplane from these data.

INTRODUCTION

The conventional test of a flying-boat hull or seaplane float, as carried out in the N.A.C.A. tank, is described in reference 1. It is made under conditions that apply only to the seaplane for which the hull was designed. The load on the model at rest is the gross load of the seaplane multiplied by the cube of the linear ratio of model to full size. At any speed the water-borne load is reduced by means of a vane running in the water and acting on the model suspension. This lifting device is so adjusted that it reduces the water-borne load to zero at the get-away speed of the model, which is equal to the get-away speed of the seaplane multiplied by the square root of the linear scale. Since the water force on the lifting vane varies as the square of the speed, neglecting scale effect, this system is equivalent to assuming that the wings of the airplane remain at a constant lift coefficient corresponding to the get-away speed chosen, and that there is no wind.

This method of testing, which may be called the "hydrovane" method, is satisfactory for studying models at speeds in the region of maximum resistance. At one half the get-away speed the water-borne load is still three quarters of the total, so that reasonable changes in the aerodynamic lift coefficient have only a slight effect upon the water resistance. At speeds near get-away, however, a relatively small change in angle of attack will produce a large change in the load on the water, hence in the water resistance.

Difficulties arise in calculating the effect of wind or a change in get-away speed from tests made with the hydrovane. Diehl proposes a method (reference 2, p. 261) based on the assumption that, for a given gross load on the hull, the ratio of load to resistance Δ/R, is the same at a given fraction of the get-away speed V/V_g, regardless of the actual value of the get-away speed. The method serves well in the absence of more definite information; however, computations based on complete data show that the results may be seriously in error, particularly at high speeds. Consequently the effect of wind, of changes in wing setting, or of wing loading cannot be studied satisfactorily unless additional tests are made covering all the conditions in which the designer may be interested.

A further disadvantage of the hydrovane method of testing is encountered in any general study of hull forms. Froude's law of model similitude (see reference 1) requires that the ratio $\frac{\Delta^{\frac{1}{6}}}{V}$ be the same for the model and the full-scale hull, at corresponding speeds, in order that data can be converted from one to the other. The model data from hydrovane tests on various hull forms can therefore be compared only when the ratio of $\frac{\Delta^{\frac{1}{6}}}{V_g}$ is the same in each instance, which is not ordinarily the case. Moreover, there is no assurance that the hulls were operating at best load; that is, a smaller or larger hull of the same form might have given better results at the design load than the hull of the size chosen.

These considerations lead to the conclusion that for research purposes it is necessary to find the water characteristics of a hull at all the speeds, loads, and trim angles that may be of interest in connection with any airplane design for which the hull is suitable. This type of test is suggested by Seewald (reference 3) and described in detail by Schroeder (reference 4). As yet there is no accumulation of data on hulls tested in this manner. As the material is made available, however, the designer will be able to select the best form and size of hull for his particular design and to determine its take-off characteristics much as he now chooses an airfoil from wind-tunnel tests.

N.A.C.A. Model No. 11 was tested by the complete method. This hull is the parent of a series developed from it by making systematic changes in length and beam. The characteristics of the other models of the family will be presented in later reports. The water characteristics of Model No. 11 are given in this note as well as an example applying the data to a design problem.

TEST OF MODEL NO. 11 BY COMPLETE METHOD

Apparatus and Procedure

The N.A.C.A. tank, its equipment, and general test procedure are described in reference 1. The lines of Model No. 11 are given in figure 1 and the offsets in table I. For the complete type of test used for this model the load on the water is adjusted by counterbalancing the model to zero displacement and then removing sufficient counterweight to equal the desired load for any test point. The center of moments (see fig. 1) is arbitrarily chosen to correspond approximately to the center-of-gravity position for this type of hull. Trim angles are measured between the horizontal and the base line of the model.

The schedule of test points is shown in figure 2. Runs are made at constant speed and trim angle. The load is varied by adjusting the counterweight. By this method several test points at the slower speeds can be obtained during one run of the towing carriage. The water resistance, draft, and moment required to hold the fixed-trim angle are measured for each point. Those combination of the independent variables - load, speed, and angle - which are obviously outside the useful working range are omitted. Enough different trim angles are tried for each load and speed, however, to establish the cross curve of resistance against trim angle, and to insure that the angle giving minimum resistance is included.

Results

Methods of deriving and presenting data.- The speed, load, trim angle, resistance, trimming moment, and draft for each test point are given in table II. Resistance and moment are plotted against speed, with load as a parameter, in figures 3 to 6. Each figure presents the characteristics of the model at one angle. The values given were obtained directly from the test data by deducting the usual tares as described in reference 1. It should be noted that the air drag of the model is included in the final resistance because there is no feasible method of determining the air drag of a model running on the water at all the drafts and trim angles encountered. The conversion of air drag from model to full scale follows the same law as that for water resistance except for errors introduced by scale effect, towing-gear interference, and differences in above-water form between the model and the full-scale hulls. Since the air drag is never large compared to the water resistance, these errors are believed to be within the accuracy of the test data. When the results are applied to a take-off calculation the parasite drag of the hull should, of course, be omitted in determining the air drag of the airplane.

The original data as given in table II and figures 3 to 6 are difficult to apply because there are three independent variables: speed, load, and trim angle. For most work one of these variables can be eliminated in the following manner. At each speed and load there is generally one trim angle for which the resistance is a minimum. So far as possible the hull should be run at this best angle. In order to determine this minimum resistance and the angle at which it occurs, the original resistance curves for each load were cross-plotted against angle for a series of speeds. These results were then cross-faired against load, at constant speed. The values were reduced to nondimensional form to simplify comparison with other hull forms.

Nondimensional coefficients.- The coefficients used are defined as follows:

Load coefficient $C_\Delta = \dfrac{\Delta}{wb^3}$

Resistance coefficient $C_R = \dfrac{R}{wb^3}$

Trimming-moment coefficient $C_M = \dfrac{M}{wb^4}$

Speed coefficient $C_V = \dfrac{V}{\sqrt{gb}}$

where	Δ,	load on the water	lb. or kg
	R,	water resistance	lb. or kg
	w,	weight density of water	lb./cu.ft. or kg/m³
	b,	beam of hull	ft. or m
	M,	trimming moment	lb.-ft. or m-kg
	V,	speed	ft./sec. or m/s
	g,	acceleration of gravity	ft./sec.² or m/s²

Note: w = 63.6 lb./cu.ft. for the water in the N.A.C.A. tank.

These coefficients were derived from Froude's law of comparison and apply to any size of hull. The beam was chosen after considerable study as the only practicable dimension to use in reducing the results to nondimensional form.

The characteristics of the model, using these coefficients, are presented in figures 7 and 8 as curves of best angle τ_o and minimum resistance coefficient C_R against speed coefficient C_V, with the load coefficient C_Δ as a parameter. Figure 9 presents the same data as figure 8, with C_Δ as the abscissa and C_V as the parameter. In this form the results can be applied to take-off calculations without interpolating for C_Δ.

Accuracy.- The order of precision attained in measuring the various quantities is as follows:

Load	±0.3 lb.
Resistance	±0.1 lb.
Speed	±0.1 ft./sec.
Trim angle	±0.1°
Trimming moment	±1.0 lb.-ft.

The moment and resistance points occasionally lie considerably farther from the curves than these limits. Such deviations, however, usually occur where the model is running under unsteady conditions, and duplication of readings would be impossible even with apparatus having no error whatever. The curves are carefully faired, and are believed to represent average values to ~~approximately~~ the precision listed.

Discussion of Results

Variation of resistance and moment with speed.- The curves in figures 3 to 6 show the behavior of the hull as a planing boat running at constant load. The resistance in every case rises to a maximum at about 16 feet per second for this model. As planing becomes effective the resistance decreases until a speed of 20 to 25 feet per second is reached. At higher speeds the resistance rises again, because of the large increase in skin friction, due in part to the blister from the main step which wets the afterbody at high speeds and light loads. An exception to this is found in the curves for loads of 5 pounds and 10 pounds at $\tau = 9°$ (fig. 6). Under these conditions the main step is clear of the water and the load is carried on the pointed second step, eliminating the interfering blister and giving low resistance. Unfortunately, the nose-heavy moment at this point is so high that this characteristic has no practical application.

The trimming-moment curves at constant angle reach a maximum positive (tail-heavy) value at approximately the speed of maximum resistance. As the speed is increased the moment drops and approaches a constant small value at the highest speeds.

Curves of best trim angle and minimum resistance.- The curves of τ_o, the angle for minimum resistance, are given in figure 7. They show that the general shape of the moment curves is satisfactory, because the best angle also reaches a maximum value at hump speed and drops off to a nearly constant value of about 4° at the higher speeds. The curves of minimum resistance (fig. 8) show the same trend of resistance against speed at constant load that has been noted for the curves at constant angle. One variation occurs at a speed coefficient of about 1.6, where there is a dip in the curve not present in the constant-angle curves, representing the point at which planing starts. The best angle increases rapidly in this region.

Application of characteristics at best angle.- The curves of best angle and minimum resistance may be used to determine the following items, which are of first importance to the designer:

1. The best beam for a given hull form, applied to a given seaplane.

2. The best angle of wing setting for a given combination.

3. The best form of hull from among those for which data from this type of test are available.

Because of the large number of variables involved, the calculations are not as simple as those required for applying a hydrovane test. As the test results on a number of hulls are accumulated and experience is gained in applying them, short cuts will no doubt suggest themselves. In any case, the method is a distinct improvement over that of guessing at the various factors, or of making the enormous number of tests of the hydrovane type necessary to establish them.

A study of the procedure for determining the best form of hull will be made in a later report, when data on several hulls are available. The results have been applied to a specific design in the example outlined in this note.

Effect of beam loading.- In order to determine the effect of beam loading upon resistance, the load/resistance ratio, Δ/R, is plotted against the load coefficient C_Δ for several values of the speed coefficient C_V. These curves are shown in figure 10. At a speed coefficient of 2.3, which corresponds to maximum resistance, Δ/R decreases with increasing C_Δ, which means that decreasing the beam (i.e., using a smaller hull) for a given load increases the hump resistance. At a somewhat higher speed coefficient (3.4 for this model) the value of Δ/R is found to be practically constant for all values of C_Δ within the range tested. As the speed is increased still more the tendency reverses, as shown by the curves for speed coefficients of 4.5 and 6.0. In the high-speed range, decreasing the beam for a given load reduces the resistance.

These tendencies, which are borne out by preliminary results on the other hulls of this type, guide the designer in his choice of the best beam for a given combination. If the first trial calculation shows low excess thrust at the hump and ample margin at high speeds, the beam should be made larger. If the margin of thrust at the hump is satisfactory but "sticking" occurs at high speed, smaller beam should be used. It should be borne in mind that whereas a given amount of excess thrust represents the same acceleration (i.e., the time required to increase the speed one mile an hour) at any speed, the distance run in each second varies directly with the speed. In order to get the best compromise of take-off time and run, the beam should be chosen to give somewhat higher excess thrust at high speeds than at the hump.

Attention is called to the fact that for a given speed and load of the airplane, when the value of C_Δ is varied by changing the beam, the speed coefficient $C_V = \frac{V}{\sqrt{gb}}$ is also changed, reducing somewhat the gain obtained when the beam is decreased in order to reduce the resistance at high speeds. A reduction of the beam increases C_Δ but also increases C_V, and in the high-speed range resistance is increasing with C_V. The change in C_V is small, however, compared with that in C_Δ, since the beam enters C_V as the one-half power and C_Δ as the cube. The tendency of narrower beams to give lower resistance at high speeds for a given speed and load of the airplane is thus unchanged.

If the speed coefficient had been chosen as $\frac{V}{g^{\frac{1}{2}}} \times \left(\frac{w}{\Delta}\right)^{\frac{1}{6}}$, a constant speed coefficient at a given load would then represent a constant full-scale speed, regardless of beam. This coefficient was not chosen, however, because the slight advantage is more than offset by the increased labor involved in the take-off calculation.

Moments at best angle.- The moment coefficients corresponding to the best-angle curves are not given. There is, of course, a definite trimming moment corresponding to each speed and load at best angle. Good curves for this quantity are very difficult to establish, however, because the moment changes rapidly with angle whereas the resistance changes only slightly with angle in the region near minimum resistance. If all the aerodynamic moments acting on the airplane were known accurately, the precision of the take-off calculation could be somewhat improved by determining the control force necessary to give the desired trim angle. The lift and drag of the horizontal control surfaces and the change in water resistance caused by the resulting change in load could then be found. This refinement does not seem to be warranted, however, and it is recommended that the moment be checked only at the hump and near the get-away by referring to the original model data to insure that the location of the center of gravity is satisfactory and the elevator control adequate.

EXAMPLE OF TAKE-OFF CALCULATION

General data for assumed flying boat.- The data for Model No. 11 will be applied to a take-off calculation for a flying boat. The following characteristics of the airplane are assumed to be given:

Gross load, Δ_o - - - - - 15,000 lb.

Wing area, S_w - - - - - - 1,000 sq.ft.

Power - - - - - - - - - - - 1,000 hp.

Effective aspect ratio, considering ground effect - - - - - - - - - - - - - 7.0

Parasite drag coefficient, excluding hull - - 0.05

Airfoil - - - Clark Y (data taken from N.A.C.A. T.R. No. 352, p. 26)

The curves of C_L and C_D for the complete airplane exclusive of hull, converted to aspect ratio 7, are given in figure 11. The air drag of the hull is included in the model resistance. It should be noted that ground effect produces an appreciable increase in effective aspect ratio, and should be allowed for. A method for computing it is given in reference 5 (p. 172).

In this example it is assumed that there is no wind.

Propeller thrust.- Accurate information on propeller thrust is necessary for determining the take-off performance of the seaplane. Curves of the engine torque and propeller thrust and torque should be used if they are available. Unfortunately, there is not much published information on propeller characteristics at low values of V/nD. An N.A.C.A. report giving such data, expressly for take-off calculations, is being prepared.

If exact information is not available, any one of several empirical methods may be used to find the thrust. Two of these are given in reference 2 (pp. 133 and 262) and reference 6. Such methods should be used with caution, however, particulary in the case of geared propellers at high pitch settings. In this case the root sections may be stalled at low forward speeds, causing a serious loss of thrust. For the present example the thrust curve has been determined by the method given in reference 2 and is shown in figure 13a.

Selection of beam.- The first step in determining the water resistance is the selection of the proper beam. A number of formulas are in common use for determining the beam but, since the best compromise depends upon the characteristics of the hull used, they are only rough guides. The curves of figure 10 offer a somewhat better means for making a first approximation, which can be corrected after the final resistance curve is constructed. The smallest beam which does not make the hump resistance seriously high should be chosen, because a small beam is favorable to low resistance in the high-speed range. Considerations of structural weight also favor a small beam. It should be noted, however, that excessive reduction in beam may cause objectionable spray characteristics.

The hump of the total resistance curve will occur at approximately the same speed coefficient as the hump of the best-angle curves in figure 8. For Model No. 11 the value of C_V at the hump is about 2.3. Referring to figure 10, the value of Δ/R for this speed is 4.5 at $C\Delta$ = 0.35. This value of Δ/R is about the lowest that will give satisfactory performance at the hump; hence the beam should not be decreased beyond this point, at least for the first trial. It may be assumed that the load Δ at the hump is roughly nine tenths of the gross load, or 13,500 pounds.

We have then:

$$C\Delta = \frac{\Delta}{wb^3} \; ; \quad 0.35 = \frac{13500}{64 \times b^3}$$

(w = 64 lb./cu.ft. for sea water)

$$b = \left(\frac{13500}{64 \times 0.35}\right)^{\frac{1}{3}} = (603)^{\frac{1}{3}} = 8.45 \text{ ft. or } 101.5 \text{ in.}$$

This value agrees reasonably well with current practice.

The following wing numerical relations can now be established:

$$C_\Delta = \frac{\Delta}{64 \times 8.45^3} = \frac{\Delta}{64 \times 603} = \frac{\Delta}{38500}$$

$$C_R = \frac{R}{38500}$$

$$C_V = \frac{V}{\sqrt{32.2 \times 8.45}} = \frac{V}{16.52}$$

$$\text{Air lift} = C_L \times \frac{1}{2} \rho V^2 \times S_w = C_L V^2 \times \frac{0.00237 \times 1000}{2}$$

$$= 1.185 \; C_L V^2$$

$$\text{Air drag} = 1.185 \; C_D V^2.$$

Selection of angle of wing setting.- The values of C_L and C_D (fig. 11) depend upon the angle of attack of the wing, which equals the trim angle τ plus the angle of wing setting. Since the air lift and drag have little effect at the hump, the wing setting should be chosen to give the least total air-plus-water resistance near the get-away. A setting giving the least resistance at a speed equal to 85 percent of the stalling speed seems to be a good compromise.

The stalling speed for this example, with $C_{L\ max}$ = 1.415, is $V_s = \left(\frac{15000}{1.185 \times 1.415}\right)^{\frac{1}{2}} = (8,950)^{\frac{1}{2}} = 94.6$ f.p.s. At 85 percent V_s, $V = 94.6 \times 0.85 = 80.4$ f.p.s.; $C_V = 4.86$; lift = $C_L \times 1.185 \times 80.4^2 = 7,650\ C_L$; drag = $7,650\ C_D$. The total resistance at this speed can now be calculated for a series of angles of attack as shown in the following table:

Determination of Angle of Wing Setting, $C_V = 4.86$

α	4°	6°	8°	10°	12°	14°
C_L	0.70	0.85	1.01	1.16	1.28	1.37
L, lb.	5360	6500	7720	8870	9780	10480
Δ, lb.	9640	8500	7280	6130	5220	4520
C_Δ	.250	.221	.189	.159	.136	.117
C_R	.0537	.0491	.0442	.0398	.0362	.0333
R, lb.	2070	1890	1700	1530	1390	1280
C_D	.084	.0975	.113	.130	.1485	.170
D, lb.	640	745	865	995	1135	1300
R + D, lb.	2710	2635	2565	2525	2525	2580

In this table the wing angle of attack α, is chosen as the independent variable. C_L is read from figure 11 at the appropriate value of α.

$$L = C_L \times 7,650$$

$$\Delta = 15,000 - L$$

$$C_\Delta = \frac{\Delta}{38500}$$

C_R is read from the curve in figure 12a at the corresponding value of C_Δ. Figure 12a was cross-plotted from figure 8 at $C_V = 4.86$ in the manner described above for the curves in figure 9.

$R = C_R \times 38,500.$

C_D is read from figure 11.

$D = C_D \times 7,650.$

The curve of total drag $R + D$, against angle of attack α, is given in figure 12b. Its minimum value occurs at $\alpha = 11^\circ$.

At this angle of attack $C_L = 1.22$, $L = 1.22 \times 7,650 = 9,340$, $\Delta = 15,000 - 9,340 = 5,660$, $C_\Delta = \frac{5660}{38500} = 0.147$.

For this value of C_Δ, at $C_V = 4.86$ (see fig. 7), the best trim angle, $\tau_o = 5.3^\circ$

The angle of wing setting to be used is then $11^\circ - 5.3^\circ = 5.7^\circ$.

This value will be used for the first approximation.

For a more accurate determination, complete take-off calculations can be made with various angles of wing setting near this value and the effect on take-off time and run found.

Calculation of resistance.- In order to read the resistance coefficient C_R from figure 9, the load coefficient C_Δ must be known for each speed. The load Δ, and consequently C_Δ, depends upon the air lift, which in turn depends upon the angle of attack, hence on the trim angle τ. The best trim angle τ_o, given in figure 7, also depends upon C_Δ, so an approximation again becomes necessary. Fortunately the curves of τ_o for all loads lie within about 1° of a mean, which is shown by a dotted line in that figure. The use of this average value of τ_o makes it possible to calculate an approximate value of C_Δ, from which a second approximation of τ_o, accurate enough for use as a final value, may be read from figure 7.

The calculation is most readily carried out in the form of table III. In this table the speed coefficient

C_V is chosen as the independent variable. Using the numerical relations already established for this example,

$V = C_V \times 16.52.$

τ in the first approximation is read from the mean curve in figure 7 at the corresponding value of C_V.

α = trim angle τ + angle of wing setting (5.7°).

C_L is read from figure 11 at the corresponding value of α.

$L = C_L \times 1.185\ V^2.$

$\Delta = 15,000 - L.$

$$C_\Delta = \frac{\Delta}{38500}.$$

τ in the second approximation is read from figure 7 at the appropriate value of C_V, interpolating between the curves of constant C_Δ to get τ_o at the value of C_Δ obtained in the first approximation.

α, C_L, L, Δ, and C_Δ for the second approximation are then obtained as before.

C_R is read from figure 9 at the appropriate values of C_V and C_Δ.

$R = C_R \times 38,500.$

C_D is read from figure 11 at the corresponding value of α from the second approximation.

$D = C_D \times 1.185\ V^2.$

<u>Calculation of take-off time</u>.- The curves of air drag D, and total resistance $R + D$, from table III, together with the thrust curve of this example, are given in figure 13a. The difference between the thrust and the value of $R + D$ at any speed represents the excess thrust T_e, available for accelerating the seaplane. If the total weight is W pounds, the acceleration $a = \dfrac{T_e}{\left(\frac{W}{g}\right)}$ where g

is the acceleration of gravity. To get the time required for take-off we have the relation

$$a = \frac{dV}{dt}, \quad dt = \frac{1}{a}\,dV$$

$$t = \int_0^{V_g} \frac{1}{a}\,dV$$

When $\frac{1}{a}$ is plotted against V the value of this integral can be obtained as the area under the curve. This curve is given in figure 13b. The area is 12.50 square inches, to a scale where 1 inch = 20 feet per second on the V axis and 1 inch = 0.2 $\frac{\text{sec.}^2}{\text{ft.}}$ on the axis of $\frac{1}{a}$. Hence 1 square inch = $20 \times 0.2 \left(\frac{\text{ft.}}{\text{sec.}} \times \frac{\text{sec.}^2}{\text{ft.}}\right) = 4$ sec. The take-off time is thus 12.5 × 4 = 50 sec.

Calculation of take-off run.- To get the distance run in take-off we have

$$V = \frac{ds}{dt} \qquad ds = V dt$$

but as shown above $dt = \frac{dV}{a}$

hence $ds = \frac{V}{a}\,dV$, $s = \int_0^{V_g} \frac{V}{a}\,dV$

The curve of $\frac{V}{a}$ against V is given in figure 13b.

The area under this curve, representing the distance run, is 7.80 square inches to a scale of 1 inch = 20 feet per second, and 1 inch = 20 seconds. One square inch thus represents 20 × 20 (ft./sec. × sec.) = 400 feet. The run is 7.80 × 400 = 3,120 feet.

Investigation of additional factors affecting resistance.- The above example should give a general idea of how the best angle data can be applied. The effect of a small decrease in beam should next be investigated, inasmuch as the low excess thrust near get-away results in a long take-off run. The effect of pulling the seaplane up to a higher angle at get-away, reducing V_g, can also be found by roferring tp the original model data. It should be borne in mind, however, that V_g should be sufficiently higher than the stalling speed to insure that a small disturbance will not stall the airplane after it has left the water. The value of V_g obtained in this example seems reasonable.

Several relatively minor factors have been neglected in this example. These include the effects of the tail load, of the vertical thrust component, and of the slip-stream on the wings. The treatment of such factors is straightforward if one has data from a complete test.

Trimming moments at critical regions.- The moments at the two critical regions have yet to be checked. For this purpose the original model data are used. The beam of the model (see fig. 1) is 17.0 inches, the full-size beam is 101.5 inches. The linear ratio of full size to model is thus $\frac{101.5}{17} = 5.97$.

The following factors, applied to the model characteristics, convert them to full-size values:

Speeds $(5.97)^{\frac{1}{2}} = 2.44$

Forces $(5.97)^3 \times \frac{64}{63.6} = 214$

Moments $(5.97)^4 \times \frac{64}{63.6} = 1,280$

The factor $\frac{64}{63.6}$ is the ratio of the density of standard sea water to that of the salt water in the tank.

The full-scale speeds at the two critical points are approximately 36 and 95 feet per second. The loads, from interpolation in table III, are 13,000 and 2,670 pounds. The trim angles are 9.3° and 4.4°. Reduced to model scale the speeds are 14.7 and 39 feet per second and the loads 60.8 and 12.5 pounds. The angles, of course, remain unchanged. The moments, from the curves of figures 3 to 6, are approximately 7.0 and -2.0 pound-feet, respectively. In full scale they represent moments of 8,950 and -2,560 pound-feet about the center of moments indicated on the line drawing (fig. 1). These can now be added to the aerodynamic moments of the airplane, obtained either from wind-tunnel test or by calculation, to insure that the center-of-gravity location and available control are satisfactory.

Concluding Remarks

It has been the purpose of this note to point out the advantages of the "complete" test over the usual hydrovane type of test, and to indicate by an example how the data can be applied to a take-off problem. No correction has been made to the model data for scale effect, which is probably small because of the comparatively large size of the model. In any case there is not yet available enough information on the subject of scale effect to furnish a satisfactory basis for correction, and the error is probably on the safe side.

Failure of the pilot to maintain the best trim angle throughout the take-off run will cause a slight increase over the calculated take-off time and run, which may be offset by the favorable factors neglected. If the best trim angle is held within 1° in the regions of low excess thrust, and within 2° or 3° for the rest of the run, the error will not be serious.

Tests of this sort on other typical models will be published as soon as the results are available. It is believed that an accumulation of these tests will furnish the designer a valuable tool for the improvement of the take-off characteristics of seaplanes.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., June 17, 1933.

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6. Diehl, Walter S.: The Calculation of Take-Off Run. T.R. No. 450, N.A.C.A., 1932.

TABLE I

Offsets of N.A.C.A. Model No. 11
(Inches)

Sta. No.	Dist. from bow	Half-breadths: Chine for'd lower and middle chine aft	Upper chine	WL1	WL2	WL3	WL4	WL5	Heights from baseline: Keel	Chine for'd and lower chine aft	Middle chine	Upper chine	B1	B2	B3	B4
				[a]12.0	10.0	8.0	6.0	4.0					[a]1.8	3.6	5.4	7.2
1/2	2.4	2.18					0.08	0.96	6.20	2.11			2.61			
1	4.8	3.80				0.04	1.14	2.60	8.08	3.08			5.02	3.19		
1 1/2	7.2	5.06				.89	2.40		9.39	4.12			6.73	4.83		
2	9.6	6.00			0.25	1.86	3.92		10.31	5.07			8.08	6.26	5.22	
3	14.4	7.24			1.80	4.28			11.59	6.66			10.00	8.52	7.32	6.68
4	19.2	7.91		0.67	3.78	7.54			12.45	7.91			11.28	10.12	9.01	8.13
5	24.0	8.28		1.98	5.89				13.02	8.93			12.10	11.18	10.26	9.35
6	28.8	8.45		3.20	7.70				13.43	9.69			12.63	11.83	11.03	10.23
7	33.6	8.49		4.07					13.70	10.15			12.95	12.20	11.45	10.70
8	38.4	8.50		4.54					13.88	10.36			13.14	12.40	11.66	10.92
9	43.2	8.50		4.77					13.96	10.44			13.22	12.48	11.74	11.00
10 for'd	48.0	8.50		4.82					14.00	10.48			13.26	12.52	11.78	11.04
10 aft	48.0	8.50							13.44	9.92						
11	52.8	8.50							12.97	9.45						
12	57.6	8.10	8.40						12.51	9.16	8.23	8.10				
13	62.4	6.97	8.11						12.04	9.16	7.57	7.09				
14	67.2	5.07	7.58						11.58	9.48	7.21	6.17				
15	72.0	2.59	6.77						11.11	10.04	7.11	5.38				
St. post	76.0	.20							10.74 7.24	10.66	7.16					
16	76.8		5.78						7.04			4.65				
17	81.6		4.61						5.91			4.00				
18	86.4		3.31						4.77			3.40				
19	91.2		1.90						3.64			2.85				
20	96.0		.40						2.50			2.33				

[a] (WL) Distance from baseline to water line (section of hull surface made by a horizontal plane parallel to baseline).

[a] (B) Distance from center line (plane of symmetry) to buttock (section of hull surface made by a vertical plane parallel to plane of symmetry).

TABLE II

Test Data for N.A.C.A. Model No. 11 Flying Boat Hull
(N.A.C.A. Tank Water Density 63.6 lb./cu.ft.)

Trim angle, $\tau = 3^\circ$

Load lb.	Speed f.p.s.	Resistance lb.	Trimming moment[1] lb.-ft.	Draft at step in.
80	6.4	7.3	-5.9	6.2
	7.9	10.9	13.4	6.2
	9.5	12.8	18.7	6.0
	10.2	16.6	27.4	5.95
70	6.5	6.6	-1.5	5.8
	8.0	9.3	10.8	5.7
	9.5	11.4	14.2	5.6
	10.9	14.1	22.2	5.6
	13.0	17.4	44.8	5.7
60	6.5	5.6	-1.5	5.4
	8.0	7.9	9.0	5.3
	9.5	10.0	10.8	5.2
	11.0	11.3	16.8	5.1
	12.9	14.6	38.8	5.3
	24.7	14.7	48.4	3.2
	31.4	13.6	25.6	2.4

Load lb.	Speed f.p.s.	Resistance lb.	Trimming moment[1] lb.-ft.	Draft at step in.
50	6.5	4.6	-2.5	5.0
	8.0	6.4	3.7	4.9
	9.5	7.7	8.1	4.8
	11.0	9.1	12.5	4.8
	12.9	12.3	34.4	4.9
	24.7	11.8	35.3	2.8
	30.4	11.3	20.3	2.2
	31.4	11.8	19.4	2.3
40	13.0	9.6	27.4	4.3
	26.6	8.8	16.8	2.4
	30.2	9.8	14.2	2.0
	36.0	11.1	11.6	1.8
30	24.7	6.7	12.5	2.2
	30.0	8.1	9.0	1.8
	31.4	8.3	9.0	1.8
	35.8	9.7	8.1	1.7
	41.1	10.6	2.8	1.5

[1] Positive trimming moment tends to raise bow

Trim angle, $\tau = 3^\circ$

Load lb.	Speed f.p.s.	Resistance lb.	Trimming moment lb.-ft.	Draft at step in.
20	24.9	4.9	6.3	2.0
	30.3	6.5	4.6	1.75
	35.6	7.6	2.8	1.5
	41.1	8.5	0.3	1.3
	45.8	9.1	-2.3	1.2
	45.9	9.3	-0.5	1.2
10	30.6	4.3	0.3	1.2
	36.4	4.9	0.3	1.15
	41.1	5.1	-1.4	1.0
	44.5	6.2	-2.3	0.95
	45.8	5.9	-2.3	1.0
	50.6	6.3	-3.2	0.9
5	30.6	2.9	-0.7	0.9
	36.4	3.4	-1.4	0.85
	41.0	3.8	-1.4	0.85
	44.3	4.1	-2.3	0.8
	45.9	3.7	-0.5	0.8
	50.5	5.1	-2.3	0.7
	51.3	4.9	-2.3	0.8

Trim angle, $\tau = 5^\circ$

Load lb.	Speed f.p.s.	Resistance lb.	Trimming moment lb.-ft.	Draft at step in.
80	5.6	4.1	-33.9	5.95
	7.3	9.7	-8.7	5.95
	8.8	12.2	-0.6	6.05
	8.9	12.2	-0.6	5.9
	10.4	14.5	7.2	5.95
	10.8	15.3	9.0	5.95
	12.1	16.8	18.7	5.85
70	5.6	4.0	-27.7	5.65
	7.3	8.4	-6.7	5.8
	8.9	10.5	-2.4	5.7
	9.0	10.8	-2.4	5.6
	10.6	12.9	5.5	5.55
	10.8	13.5	5.5	5.5
	12.1	14.3	17.0	5.45
	20.9	17.3	54.5	3.9
60	5.6	3.7	-23.4	5.3
	7.3	7.0	-7.6	5.4
	8.9	9.1	-4.1	5.25
	9.0	9.1	-3.3	5.2
	10.6	10.7	3.0	5.15
	10.8	10.7	3.7	5.1
	12.0	12.0	14.3	5.1
	14.0	15.2	38.6	5.0
	19.0	15.0	52.0	4.1
	21.2	13.8	42.2	3.4
	23.1	12.7	32.7	3.1
	25.3	12.0	24.7	2.65

TABLE II (Continued)

Test Data for N.A.C.A. Model No. 11 Flying Boat Hull
(N.A.C.A. Tank water density 63.6 lb./cu.ft.)
Trim angle, τ = 5°

Load lb.	Speed f.p.s.	Resistance lb.	Trimming moment lb.-ft.	Draft at step in.
50	5.6	3.3	-21.6	4.95
	7.3	5.5	-7.6	4.9
	8.9	7.6	-5.0	4.85
	9.0	7.6	-4.9	4.8
	10.4	8.1	0.3	4.7
	11.0	8.3	2.0	4.65
	12.0	9.9	8.1	4.65
	14.1	12.4	31.7	4.55
	15.6	12.6	37.2	4.2
	17.4	12.2	38.6	3.9
	18.9	11.2	34.4	3.65
	21.1	10.6	27.5	3.0
	23.1	10.0	17.8	2.65
	25.3	9.9	15.2	2.45
	30.9	10.5	8.1	2.05
40	14.1	8.9	21.3	3.9
	15.6	9.4	24.7	3.65
	17.4	9.1	26.6	3.4
	18.9	8.3	19.5	3.05
	20.8	7.8	15.2	2.7
	23.1	7.7	9.8	2.4
	25.5	7.9	9.0	2.3
	30.9	8.5	3.7	1.9
	31.4	8.7	6.3	1.9
	34.6	9.1	3.0	1.8
	37.0	9.7	1.2	1.8

Load lb.	Speed f.p.s.	Resistance lb.	Trimming moment lb.-ft.	Draft at step in.
30	23.2	5.5	4.6	2.15
	25.3	6.6	3.7	2.1
	30.9	7.3	1.2	1.65
	31.4	7.0	3.0	1.7
	36.5	8.7	-2.4	1.45
	36.8	8.5	-0.6	1.6
	38.5	9.3	-1.5	1.45
	42.5	9.4	-3.3	1.3
20	25.4	4.2	0.3	1.7
	30.0	5.7	-1.5	1.45
	31.4	5.6	0.3	1.4
	36.6	6.8	-3.3	1.3
	39.1	6.9	-3.3	1.3
	41.5	7.3	-3.3	1.3
	45.3	8.5	-3.3	1.15
	41.5	7.3	-3.3	1.3
10	30.2	3.6	-3.3	1.1
	37.4	4.2	-3.3	1.1
	38.7	5.0	-2.4	1.0
	44.3	6.3	-3.3	0.9
	45.2	6.1	-3.3	0.9
	51.5	6.7	-5.0	0.9
5	31.4	2.3	-2.4	0.85
	36.5	3.3	-3.3	0.8
	40.1	3.4	-1.5	0.8
	44.1	4.4	-2.4	0.8
	51.0	5.6	-4.1	0.8
	51.1	5.1	-4.1	0.7

Trim angle, τ = 7°

Load lb.	Speed f.p.s.	Resistance lb.	Trimming moment lb.-ft.	Draft at step in.
80	10.6	14.5	-12.2	5.7
	12.0	15.2	1.0	5.5
70	10.6	12.0	-9.4	5.2
	11.8	13.0	-0.7	5.1
	13.7	16.1	23.0	5.0
	15.6	17.6	41.4	4.8
	17.4	17.2	44.9	4.2
	18.5	16.4	41.4	4.1
	20.3	15.3	35.3	3.4
60	10.6	9.6	-10.3	4.8
	12.0	11.0	0.0	4.75
	13.9	13.6	20.4	4.55
	15.6	13.9	29.9	4.2
	17.7	13.4	32.6	3.8
	18.6	13.8	25.6	3.6
	20.3	12.3	22.1	3.0
	23.9	10.8	7.3	2.4
	26.4	11.3	5.5	2.3

Load lb.	Speed f.p.s.	Resistance lb.	Trimming moment lb.-ft.	Draft at step in.
50	10.7	7.8	-9.4	4.3
	12.3	9.0	4.6	4.25
	13.9	10.5	16.8	4.2
	15.4	11.0	18.6	3.7
	17.7	10.5	18.6	3.3
	18.7	9.9	14.2	3.15
	20.3	9.6	10.7	2.6
	23.6	9.1	3.7	2.2
	26.5	9.5	1.9	2.2
	30.6	10.1	-2.4	1.7
	31.7	10.2	-3.2	1.7
40	13.9	7.5	8.1	3.4
	15.3	7.9	9.0	3.1
	17.2	7.4	8.9	2.8
	18.7	7.3	7.3	2.7
	20.4	7.4	6.4	2.2
	23.8	7.2	1.9	2.0
	26.5	7.5	0.2	1.8
	31.6	8.9	-5.2	1.5
	36.5	10.0	-7.2	1.4
	36.6	11.1	-7.7	1.4

TABLE II (Continued)

Test Data for N.A.C.A. Model No. 11 Flying Boat Hull
(N.A.C.A. Tank water density 63.6 lb./cu.ft.)

Trim angle, $\tau = 7^\circ$

Load lb.	Speed f.p.s.	Resistance lb.	Trimming moment lb.-ft.	Draft at step in.
30	23.4	5.8	-0.7	1.9
	26.4	6.2	-2.4	1.55
	31.6	7.3	-6.7	1.3
	37.0	8.4	-8.5	1.2
	40.3	9.9	-10.2	1.1
20	26.5	5.1	-4.2	1.35
	31.6	5.9	-5.9	1.05
	36.6	7.0	-7.7	1.0
	39.6	8.4	-7.6	0.9
	40.5	8.2	-7.6	1.0
	46.1	10.0	-8.5	0.85
10	31.2	4.4	-4.2	0.8
	36.8	5.6	-5.2	0.75
	40.1	6.6	-4.2	0.75
	40.5	6.8	-6.0	0.75
	46.0	8.4	-5.9	0.8
	51.0	9.5	-6.8	0.7
5	30.8	3.3	-2.4	0.7
	31.2	3.9	-4.2	0.65
	34.2	4.1	-2.4	0.7
	36.4	4.7	-2.4	0.6
	36.5	4.8	-3.3	0.75
	38.6	6.1	-4.2	0.6
	40.6	5.8	-3.3	0.6
	45.8	7.5	-5.0	0.65
	51.4	8.5	-5.9	0.6

Trim angle, $\tau = 9^\circ$

Load lb.	Speed f.p.s.	Resistance lb.	Trimming moment lb.-ft.	Draft at step in.
80	12.1	15.0	-17.3	5.1
	13.7	18.2	9.8	5.1
70	12.4	12.8	-10.4	4.7
	13.9	15.8	10.7	4.7
	16.4	16.5	20.3	4.0
	16.5	15.7	22.0	3.95
	17.6	15.7	19.5	3.65
	18.0	15.5	21.1	3.5
	19.0	15.4	15.0	3.4
	19.4	15.4	16.7	3.25
	21.0	14.0	6.3	2.75
60	12.4	11.3	-10.4	4.25
	14.2	12.5	7.1	4.0
	16.4	13.0	9.8	3.4
	16.5	13.0	9.8	3.45
	17.6	12.9	9.6	3.25
	18.0	12.7	8.0	3.1
	19.0	12.6	5.5	2.9
	21.1	12.1	1.0	2.5
	23.7	11.9	-2.4	2.15
	24.3	12.0	-2.4	2.2
	26.3	12.7	-3.4	2.0

Trim angle, $\tau = 9^\circ$

Load lb.	Speed f.p.s.	Resistance lb.	Trimming moment lb.-ft.	Draft at step in.
50	12.3	9.4	-11.2	3.8
	14.0	10.1	-1.6	3.45
	16.4	10.2	0.1	3.0
	16.5	10.2	1.1	3.0
	17.0	10.4	2.8	2.85
	17.5	10.2	1.1	2.8
	18.4	10.0	-1.6	2.65
	21.0	10.0	-1.6	2.3
	23.6	9.9	-4.2	2.05
	24.5	10.3	-5.2	1.9
	26.4	10.7	-6.0	1.8
	32.0	12.4	-13.8	1.45
40	14.1	7.5	-6.0	2.85
	15.7	7.6	-5.2	2.5
	16.6	7.7	-6.0	2.45
	17.2	8.1	-6.0	2.5
	17.5	7.8	-5.2	2.45
	18.4	7.7	-3.4	2.35
	21.0	8.1	-3.4	2.1
	23.6	8.4	-6.0	1.85
	26.6	9.0	-8.5	1.6
	31.8	10.7	-14.7	1.3
	31.9	10.7	-13.9	1.35
	36.8	13.3	-20.9	1.1

Load lb.	Speed f.p.s.	Resistance lb.	Trimming moment lb.-ft.	Draft at step in.
30	24.0	6.3	-8.5	1.35
	26.8	7.6	-9.4	1.4
	32.1	9.3	-14.7	1.15
	32.1	8.9	-14.7	1.15
	37.4	11.1	-20.9	0.9
	41.6	12.9	-24.3	0.9
20	26.9	6.03	-10.5	1.15
	31.7	7.52	-14.7	0.9
	37.2	9.3	-20.9	0.7
	41.7	10.0	-25.2	0.7
	46.5	6.0	-36.6	0.1
10	32.0	3.3	-15.5	0.3
	35.5	2.9	-16.4	-0.5
	41.0	3.7	-19.0	-0.2
	46.5	2.6	-11.2	-0.3
	48.9	3.7	-17.3	-0.3
	51.2	3.4	-15.5	-0.1
5	32.3	1.5	-10.3	-0.3
	35.2	2.2	-7.0	-0.25
	41.0	2.0	-7.7	-0.3
	46.2	2.2	-7.7	-0.4
	47.1	1.8	-7.7	-0.45
	51.2	2.0	-9.5	-0.4

TABLE III

Resistance Calculation

C_V	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5
V fps.	16.5	19.8	23.2	26.4	29.7	33.0	36.4	39.7	43.0	46.3	49.6	57.9	66.1	74.4	82.7	90.9	99.2	107.4
[2] τ^o	4.7	4.5	5.0	6.8	7.9	8.7	9.3	9.1	8.7	8.2	7.8	7.1	6.5	5.6	5.1	4.7	4.4	4.2
α^o	10.4	10.2	10.7	12.5	13.6	14.4	15.0	14.8	14.4	13.9	13.5	12.8	12.2	11.3	10.8	10.4	10.1	9.9
C_L	1.18	1.17	1.20	1.31	1.36	1.39	1.41	1.40	1.39	1.37	1.35	1.32	1.29	1.24	1.21	1.18	1.16	1.15
L lb.	380	540	770	1080	1420	1790	2210	2620	3050	3490	3940	5250	6680	8100	9820	11550	13550	[1]15750
Δ lb.	14620	14460	14230	13920	13580	13210	12790	12380	11950	11510	11060	9750	8320	6900	5180	3450	1450	
C_Δ	.380	.375	.370	.362	.352	.343	.332	.321	.310	.299	.287	.254	.216	.179	.134	.090	.038	
τ^o	4.9	4.6	5.1	6.9	8.2	8.8	9.3	9.1	8.7	8.2	7.8	7.0	6.4	5.6	5.2	4.8	4.0	
α^o	10.6	10.3	10.8	12.6	13.9	14.5	15.0	14.8	14.4	13.9	13.5	13.7	12.1	11.3	10.9	10.5	9.7	
C_L	1.20	1.18	1.21	1.31	1.37	1.39	1.41	1.40	1.39	1.37	1.35	1.32	1.29	1.24	1.22	1.19	1.13	
L lb.	390	550	780	1080	1430	1790	2210	2620	3050	3490	3940	5250	6680	8100	9900	11650	13200	
Δ lb.	14610	14450	14220	13920	13570	13210	12790	12380	11950	11510	11060	9750	8320	6900	5100	3350	1800	
C_Δ	.380	.375	.370	.362	.352	.343	.332	.321	.310	.299	.287	.254	.216	.179	.132	.087	.047	
C_R	.0355	.0504	.0598	.0610	.0630	.0705	.0715	.0690	.0650	.0611	.0560	.0466	.0427	.0402	.0370	.0331	.0270	
R lb.	1370	1940	2300	2350	2430	2720	2750	2660	2500	2350	2160	1790	1640	1550	1430	1270	1040	
C_D	.135	.133	.137	.155	.169	.176	.181	.179	.175	.169	.165	.156	.150	.142	.138	.135	.127	
D lb.	43	63	87	128	177	227	284	335	384	428	480	617	776	928	1120	1320	1480	
R+D lb.	1413	2002	2387	2478	2607	2947	3034	2995	2884	2778	2640	2407	2416	2478	2550	2590	2520	

[1] Assuming angle at get-away $\alpha = 9.5^\circ$ $\quad C_L = 1.12 \quad v_g = \left(\dfrac{15000}{1.185 \times 1.12}\right)^{\frac{1}{2}} = 106$ f.p.s.

C_D at get-away = 0.125 $\quad$ D = 1,660 lb.

[2] First approximation.

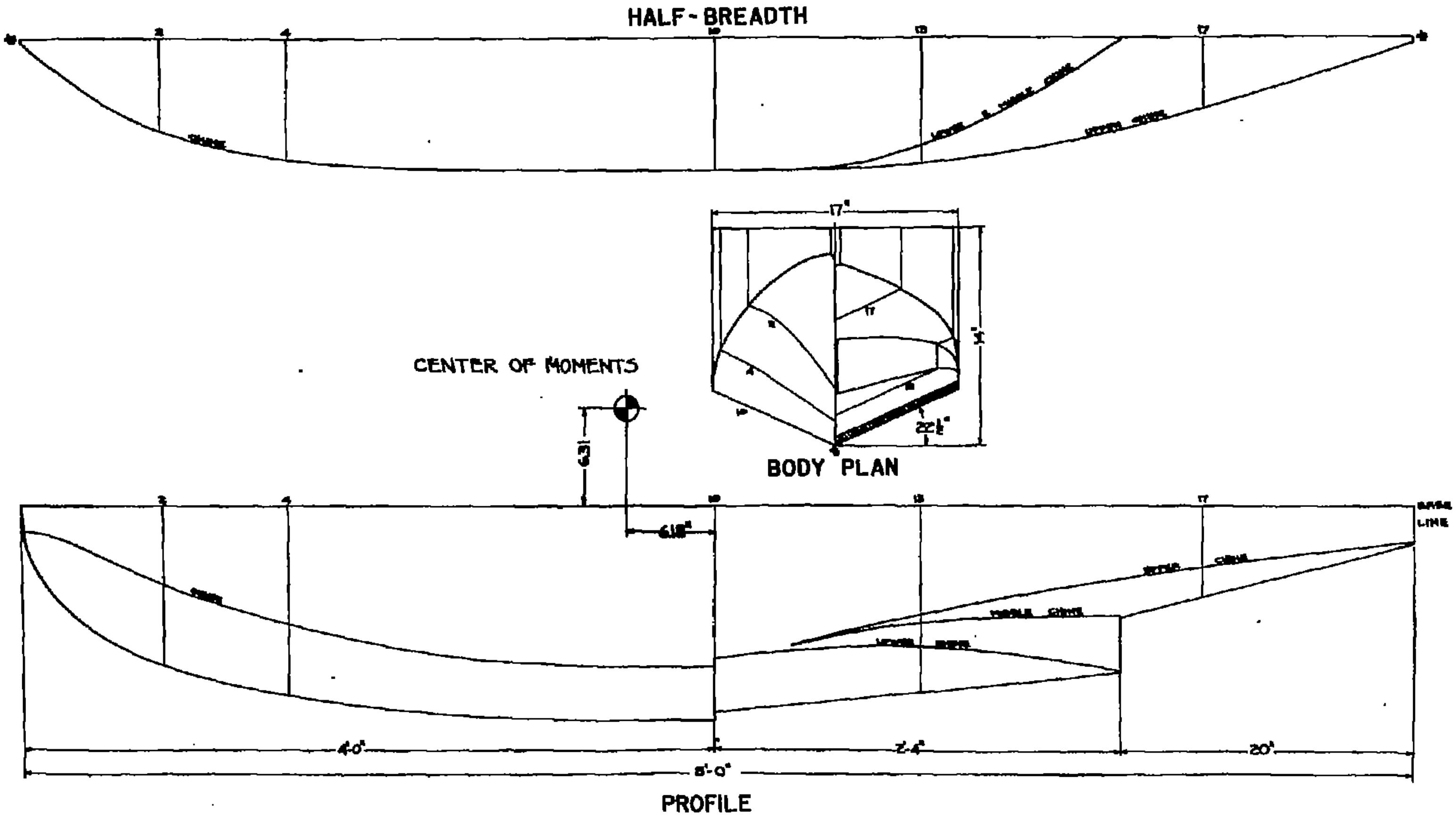


Figure 1.-Lines of N.A.C.A. Model No. 11

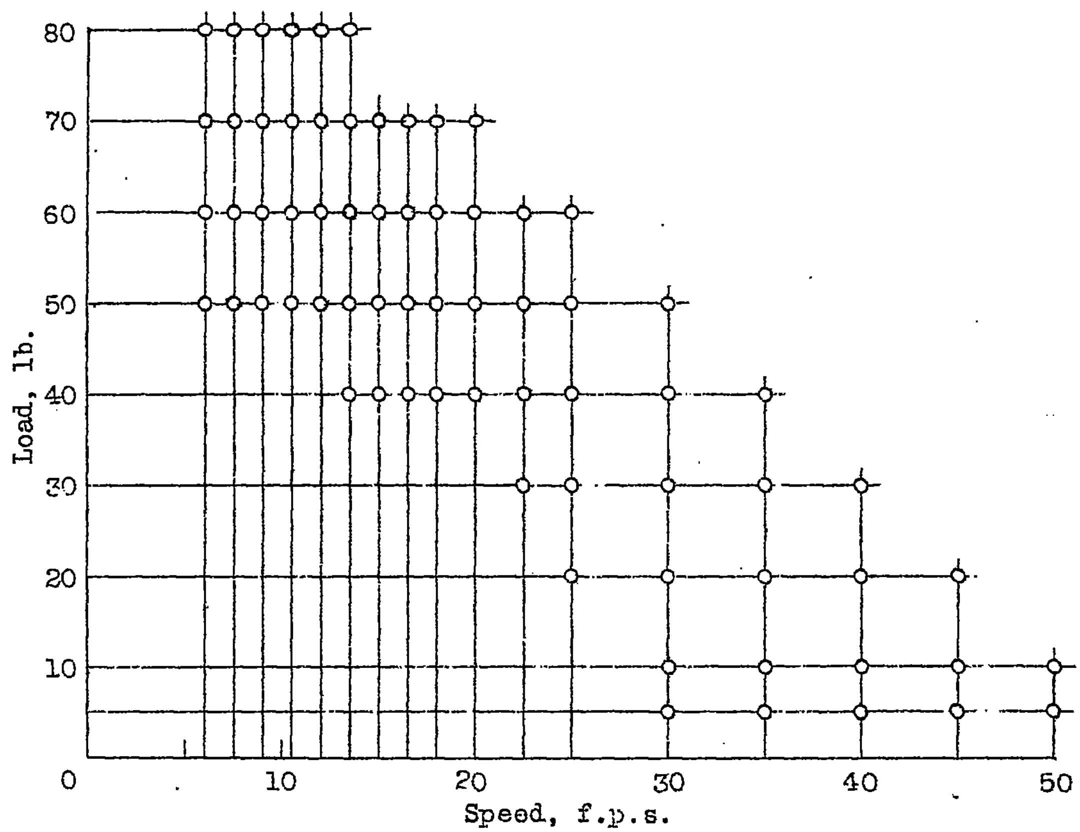


Figure 2.-Load schedule for τ = 3°, 5°, 7°, and 9°

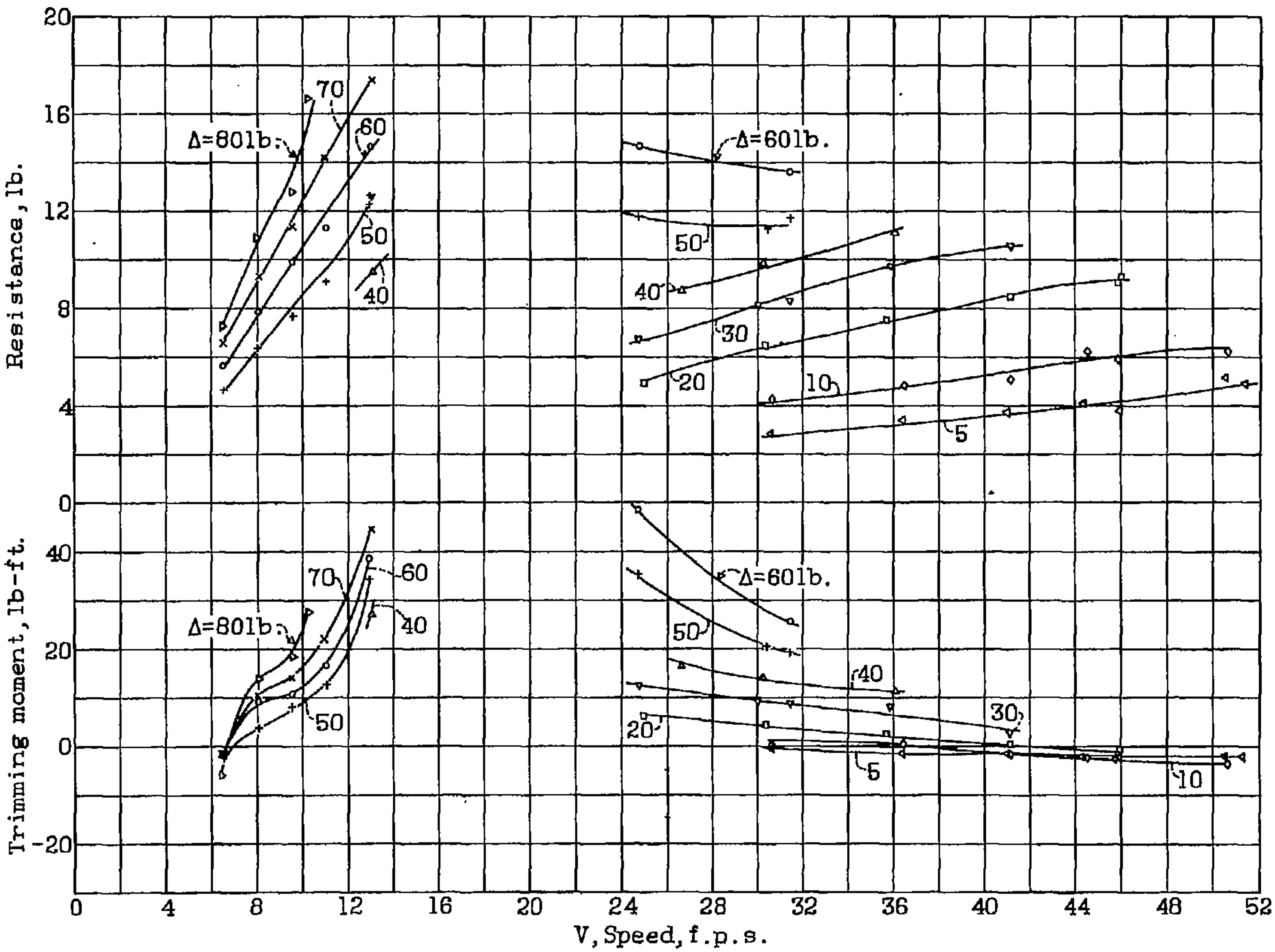


Figure 3.-N.A.C.A. tank test data for flying-boat hull Model No.11, τ = 3°.

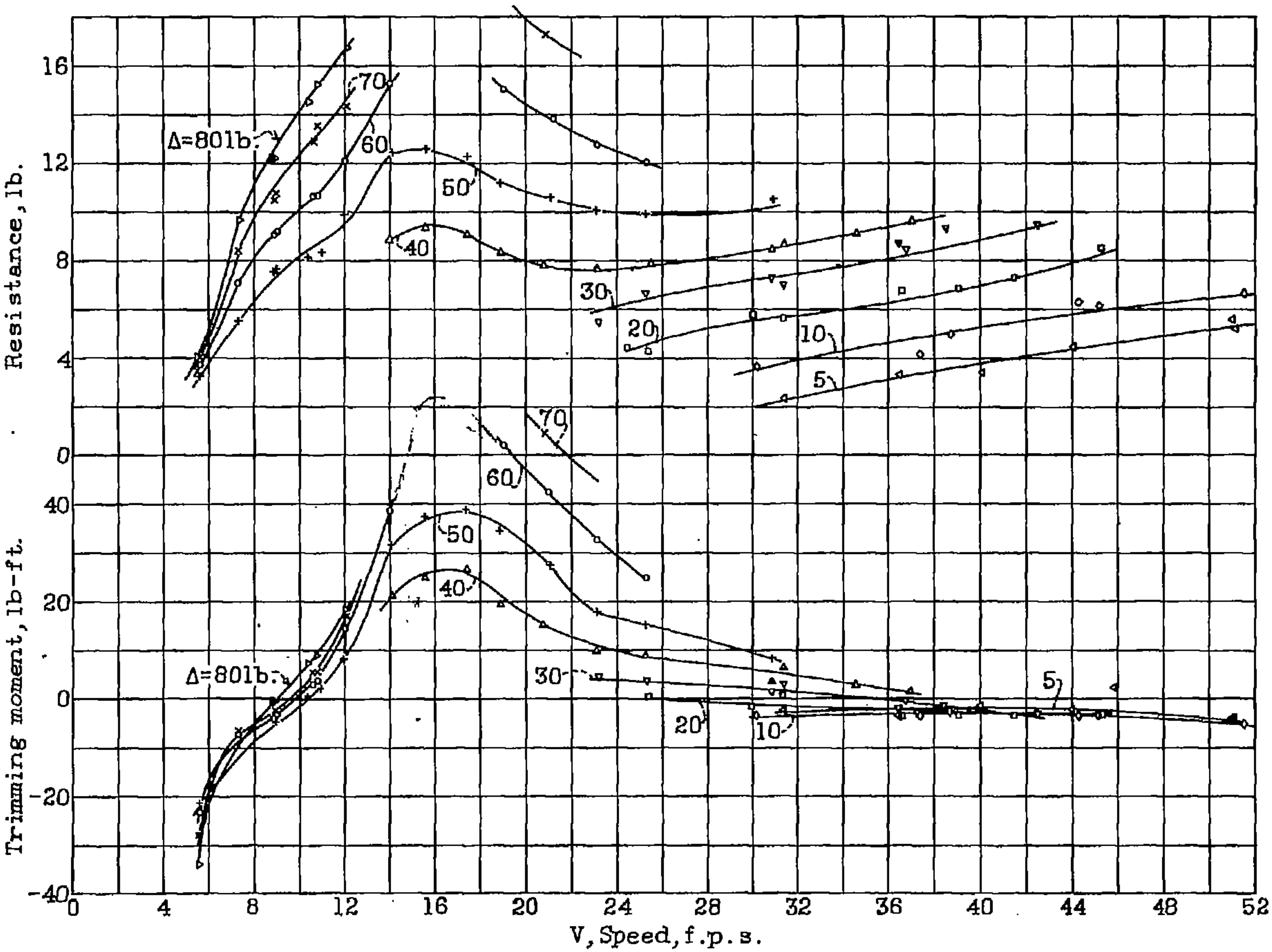


Figure 4.-N.A.C.A. tank test data for flying-boat hull Model No. 11, $\tau = 5°$.

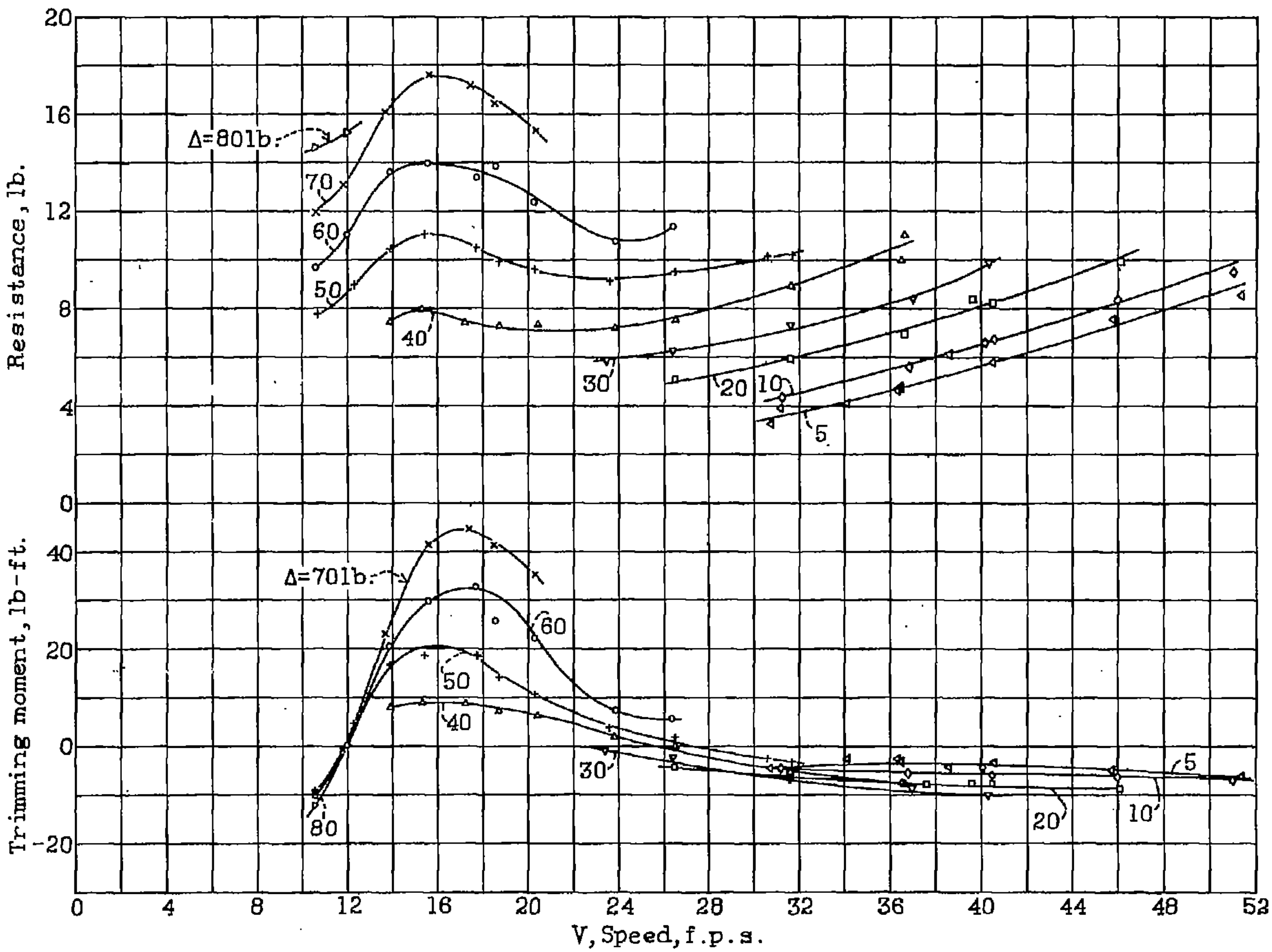


Figure 5.-N.A.C.A. tank test data for flying-boat hull Model No.11, τ = 7°.

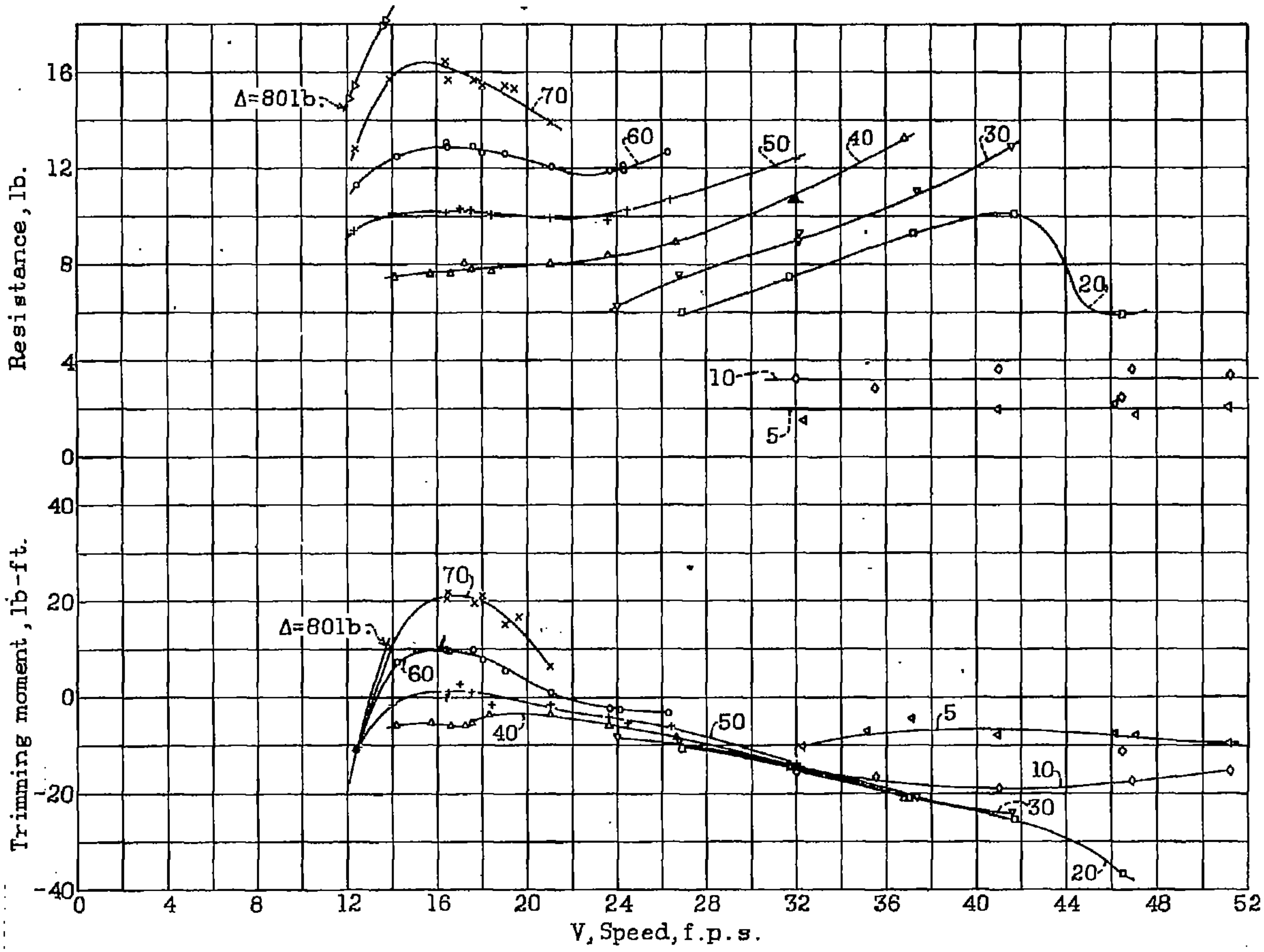


Figure 6.-N.A.C.A. tank test data for flying-boat hull Model No.11, τ = 9°.

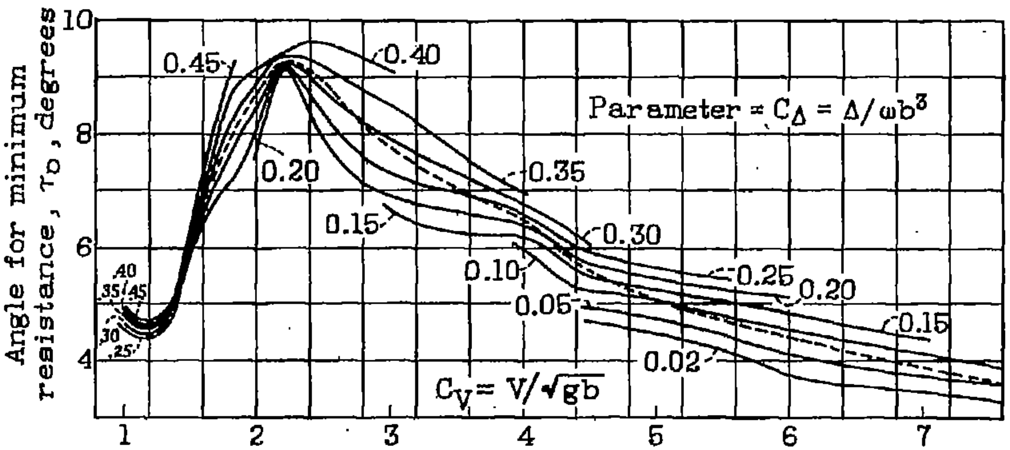


Figure 7.-Variation of angle for minimum resistance, τ_o, with speed coef., C_V.

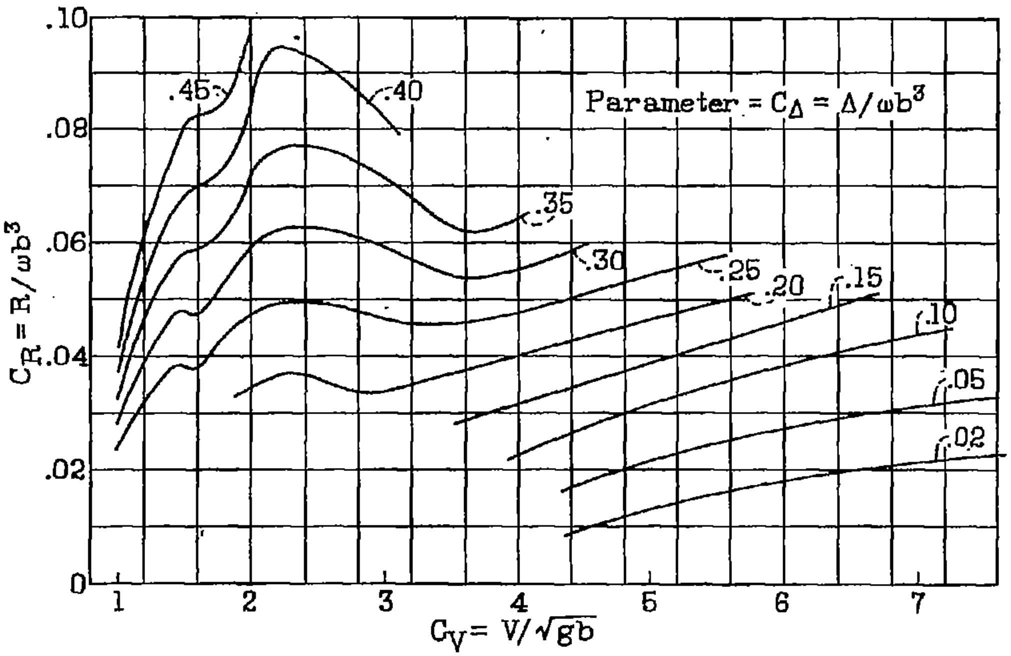


Figure 8.-Resistance coefficient at best trim angles.

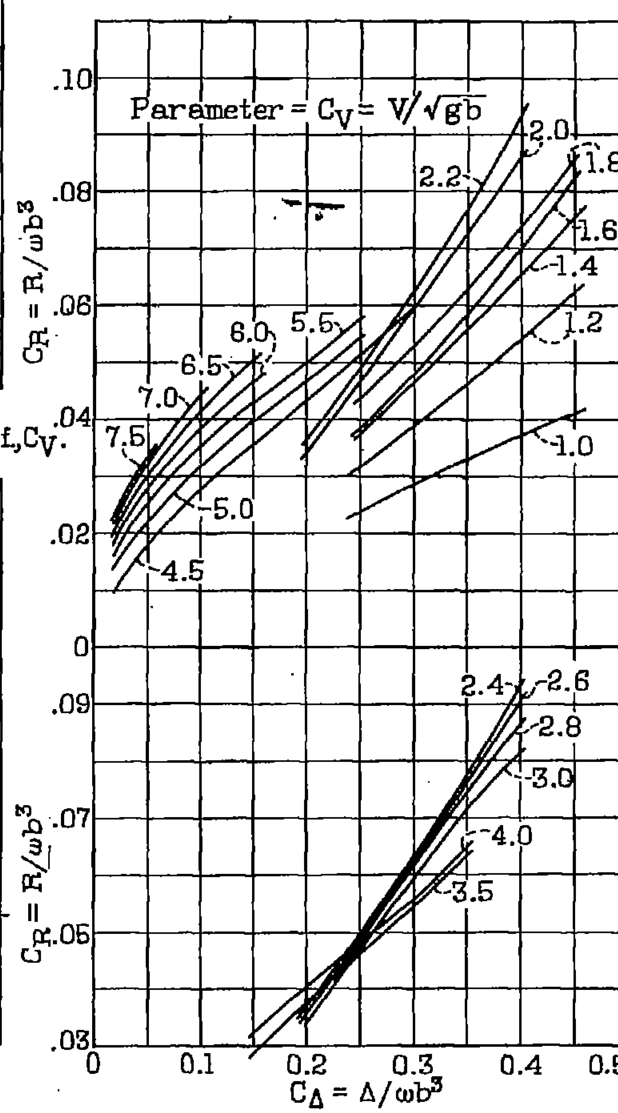


Figure 9.- C_R against C_Δ at best trim angles.

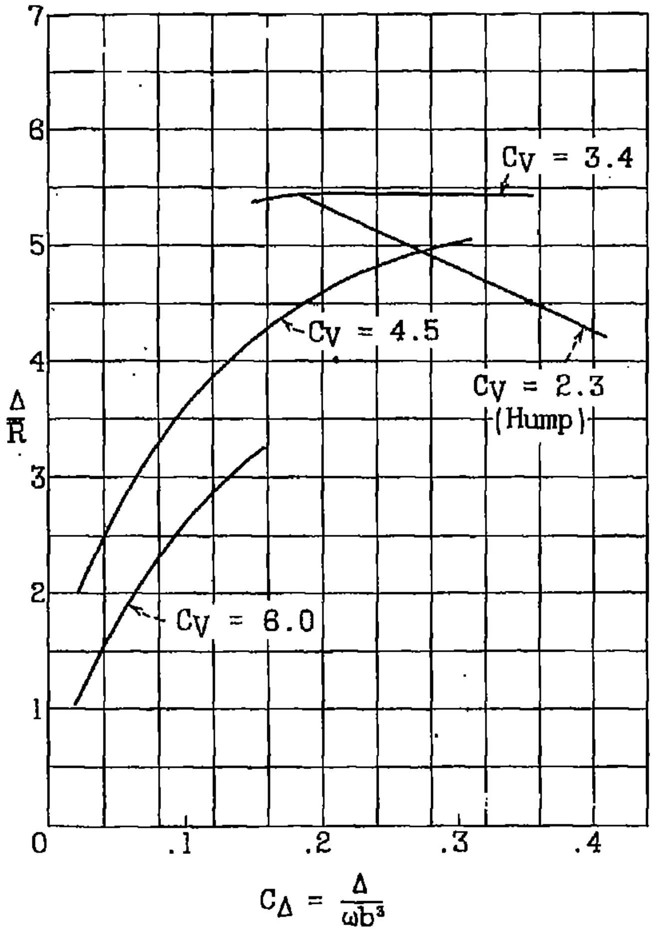


Figure 10.-Effect of C_Δ on Δ/R at best trim angles

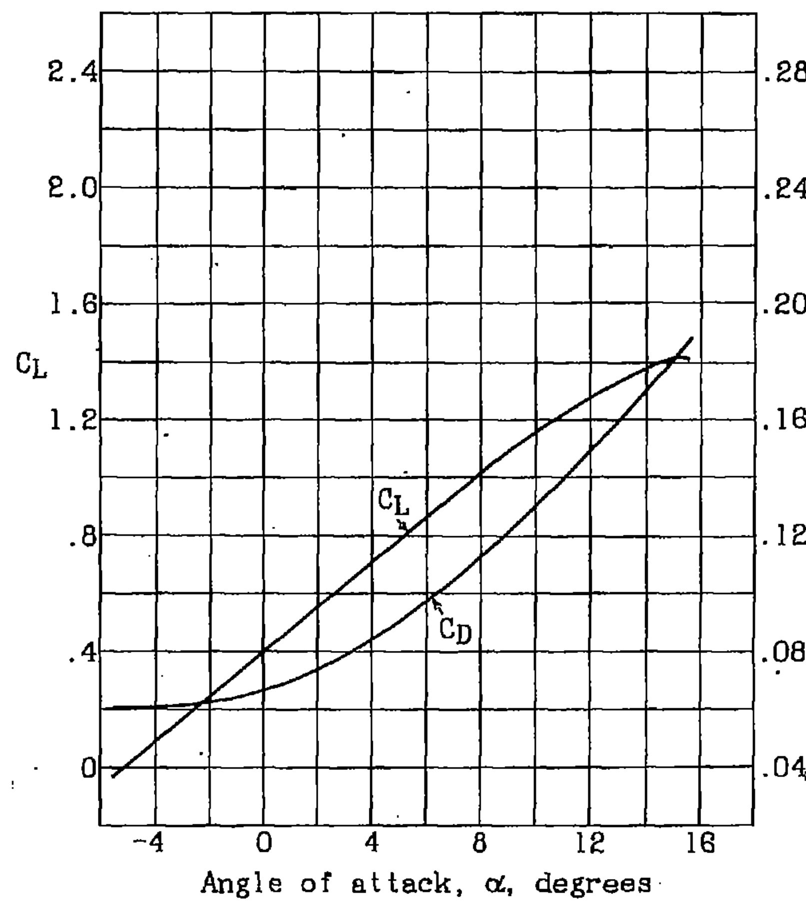
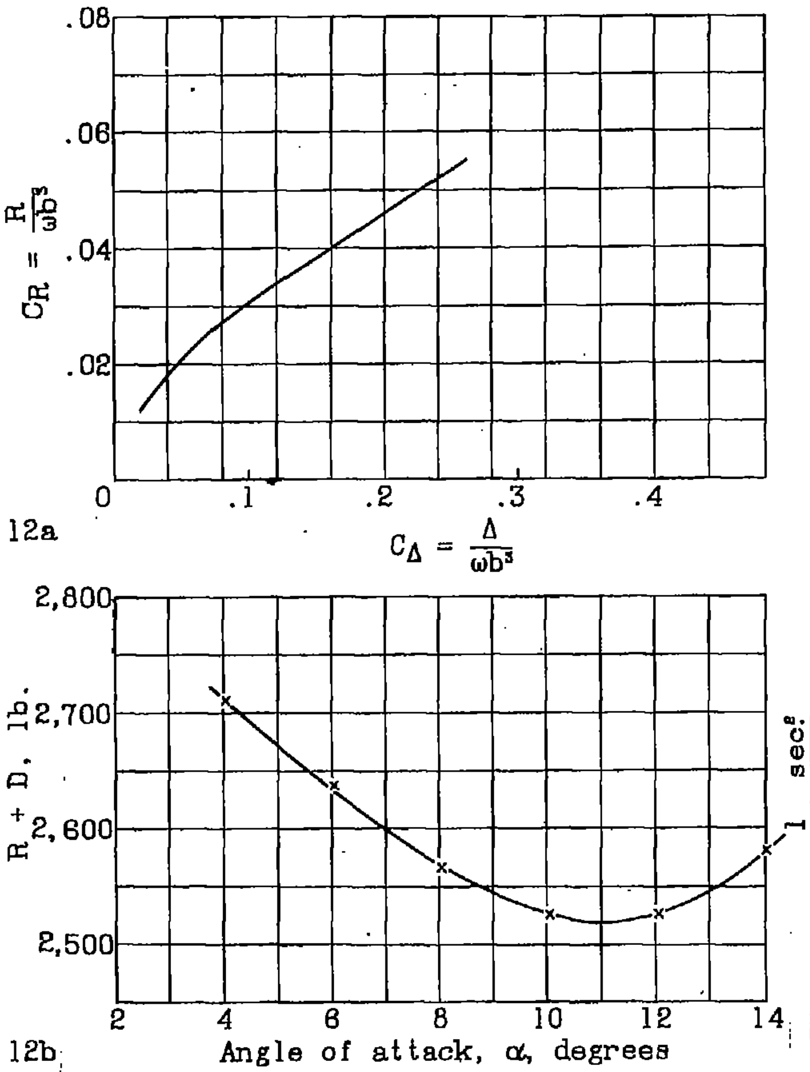
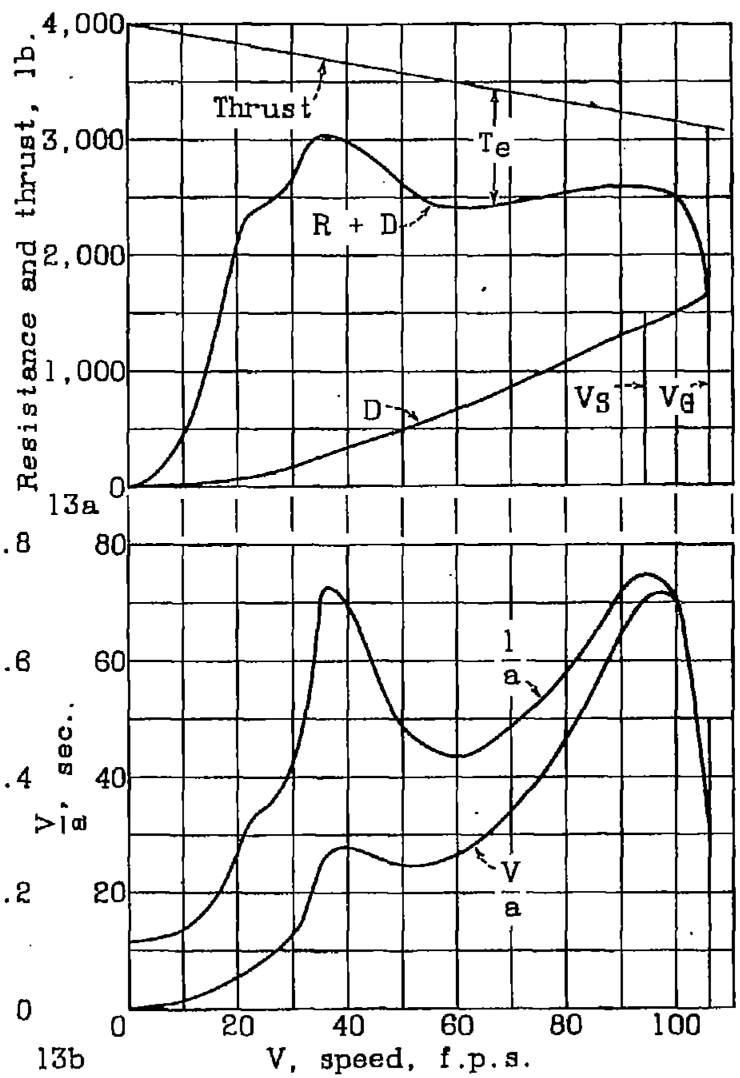


Figure 11.-Lift and drag coefficients for 15,000-lb. flying boat using Model No.11 hull.



Figures 12a and 12b.-Curves used in determination of best angle of wing setting at C_V=4.86



Figures 13a and 13b.-Take-off characteristics of 15,000-lb.flying boat using Model No.11 hull.